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ORIGINAL ARTICLES.

Notes on the Tertiary of Southern Lower California (Mexico).

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(PLATES XXI AND XXII.)

INTRODUCTION.

DURING spring and summer of 1915, an expedition was sent to the peninsula of Lower California (Baja California) by a Swiss Colonization Company. The scientific work was under the direction of the writer, who enjoyed excellent assistance from his friends Prof. Dr. Ad. Hartmann, of Aarau, and Top. Eng. E. Kluth, of Zürich. Although little time was available for stratigraphic studies, some of our observations of that almost unknown country seem to be worthy of publication.

In fact, some 10,000 square miles, hitherto regarded as Cretaceous, have been found to consist of Tertiary formations, subdivided by several unconformities, and covered by volcanoes and lava fields.

Originally, a large volume with maps, sections, and photographs was planned, containing Geography, Biology, and Geology. This plan was frustrated by several misfortunes.

The whole collection of rock samples, which was addressed and despatched for presentation to the Mineralogical Museum of the University of Zürich, after having been held up at New York, was thrown away by the American Express Co., in September, 1918, according to an investigation made by the Minister for Switzerland, at Washington, D.C. None of these rocks, especially those of the crystalline series of Magdalena and Cape Range, have yet been described.

The collection of Tertiary fossils was transmitted in 1915 to Dr. Ralph Arnold, of Los Angeles, Cal., who kindly agreed to make a close study of them, and to publish his paleontological results in a joint paper with the author. Unfortunately, his war work prevented him from undertaking this study. He therefore transmitted the fossils to Professor Dr. Bruce L. Clark, of California University. The first determinations, by Ralph Arnold and B. L. Clark, were published in the Bulletin of the Geological Society of

America, in 1917. They seem to correspond closely with the stratigraphic divisions of the authors' preliminary notes. However, according to letters from Dr. Arnold and Professor Clark, some objections have been made by a United States geologist, who recently has visited the region of La Purisima. He considers the Purisima Nueva Formation as identical with the Isidro Formation, and suggests the elimination of the name of Purisima Nueva Formation. This delicate question will be discussed under the preliminary classification, which is maintained with reservation.

Most of the balance of the fossil collection is formed of casts only, which do not render possible a specific determination. The genera are given according to Professor Clark, to whom the writer is much indebted.

Previous Investigations.

The previous knowledge of the stratigraphy of Southern Lower California was fully cited and discussed in 1912 by Bailey Willis,[1] according to the "Geologic Map of North America" by B. Willis and G. W. Stose. The most important question discussed by Willis is the determination of the age of the so-called Mesa Sandstone (Mesa = table).

Gabb [2] considered the Mesa Sandstone to be probably of Miocene age, while the later authors, Lindgren, Emmons, and Merrill, regarded it as Cretaceous. Willis followed these latter authors, according to the following quotation from his book: "The Mesa sandstones of Lower California, which were described by Gabb on very slight evidence as possibly Miocene, are here assigned to the Upper Cretaceous on the evidence of their similarity to the sandstone of that age which occurs at Ensenada." Thus, with the exception of some Quaternary along the coast, the entire peninsula from Todos Santos and La Paz in the south to Punta Abrojos (26° 45′ Lat. N.) was considered to be of Upper Cretaceous age.

Indeed, after having been ashore at Santa Catarina Landing on the west coast (Lat. 29° 31½′) the author was able to confirm the Upper Cretaceous age of the "Mesa Sandstone" of that northern part of the peninsula by finding fragments of big *Inoceramus* already reported by Merrill.[3] *All the "Mesa Sandstones" of the southern part of the peninsula, however, as far as the writer was able to determine, are exclusively of Tertiary age.* As in California, U.S.A., the Tertiary beds of Lower California are divisible into a number of different formations or groups separated by well-defined unconformities. The name of "Mesa Sandstone", therefore, can no longer be applied to these beds.

[1] B. Willis, *Index U.S. Geol. Survey*, Prof. paper 71, pp. 644–8.

[2] W. M. Gabb, *Report of J. Ross Browne on the Mineral Resources of the States and Territories west of the Rocky Mountains*, 1868, pp. 630–9.

[3] George P. Merrill, "Notes on the Geol. and Nat. History of the Peninsula of Lower California," *Report of the U.S. National Museum*, 1895, p. 976.

As a result of the writer's expedition, several preliminary papers have been published.[1]

General Structure.

Orographically and geologically, the southern part of the Lower Californian Peninsula is divided into three distinctly different regions (Fig. 1) :—

(1) The *Cape Range* or *Sierra de la Victoria*, which forms the mountainous southernmost extremity of the Peninsula, from Cape San Lucas to La Paz, with a direction from south to north. It is chiefly formed by old acid crystalline rocks : granite, syenite, porphyry, quartz-porphyry ; also dioritic rocks in places (San Antonio), with many metamorphic rocks like ortho- and paragneiss, mica-schists, and marbles (Todos Santos), amphibolite (San Antonio). They contain rich gold and silver veins at El Triunfo and San Antonio. A region of younger Tertiary sandstones has been found at the mouth of Santiago Valley on the Gulf coast (indicated with points in Fig. 1).

(2) The *Magdalena Range* (black in Fig. 1). This mountain range, which rises from the Pacific Ocean, has been partly submerged. Only the ruins of it are left. Actually, it has again entered a stage of emersion. Beginning in the south, it is represented by the bare mountainous islands of Santa Margarita, Magdalena, and San Lucas Mountain. Farther north it is represented again by the Sierra Pintada or Sierra Santa Clara, which forms the Pacific coast from Punta Abrojos (Lat. 26° 40′) to Cape San Eugenio, and terminates at Cedros Island. The distance from Santa Margarita to Cedros Island is 600 kilometres.

The rocks seem to be chiefly basic : diorite, amphibolite, and chloritic schists. No granite was encountered. Mesozoic and Tertiary intrusions of basic rocks were found on Santa Margarita and Cedros Islands. White marbles and gray, hard sandstone of great thickness, intensely folded, occur on Santa Margarita Island. No fossils were found. The sandstones are pierced by green rocks, which are partly much metamorphosed and contain hornblende, biotite, and chlorite.

(3) *The Mesas* or Central region extends from one side of the Peninsula to the other, gradually rising from the Pacific coast

[1] Arn. Heim, " Sur la géologie de la partie méridionale de la Basse Californie," *Comptes rendus Ac. d. Sc. Paris*, t. 161, p. 419, 4th October, 1915. H. Douvillé, " Les Orbitoides de la presqu'île de Californie," *Comptes rendus Ac. d. Sc. Paris*, t. 161, p. 409, 4th October, 1915. Arn. Heim, " Reisen im südlichen Teil der Halbinsel Niederkalifornien " (4 pl.), *Zeitschrift der Ges. f. Erkunde*, Berlin, 1916. Arn. Heim, " Charakterpflanzen der Halbinsel Niederkalifornien" (12 pl.), in *Vegetationsbilder v. Karsten & Schenk*, Jena, 1916. Ad. Hartmann, " Wasseruntersuchungen im Gebiete der Magdalena Bay in Niederkalifornien " (2 pl.), *Vierteljahrsschrift d. Nat. Ges. Zürich*, 1919. Ad. Hartmann, " Ein Beitrag zur Kolonisationsfrage des Westens von Nordamerika," *Mitt. Aarg. Nat. Ges.*, Aarau, 1919. Arn. Heim, " Vulkane in der Umgebung der Oase La Purisima auf der Halbinsel Niederkalifornien " (1 map, 3 pl., 7 fig.), *Zeitschr. für Vulkanologie, herausgeg. v. Imm. Friedländer*, Bd. vi, 1921.

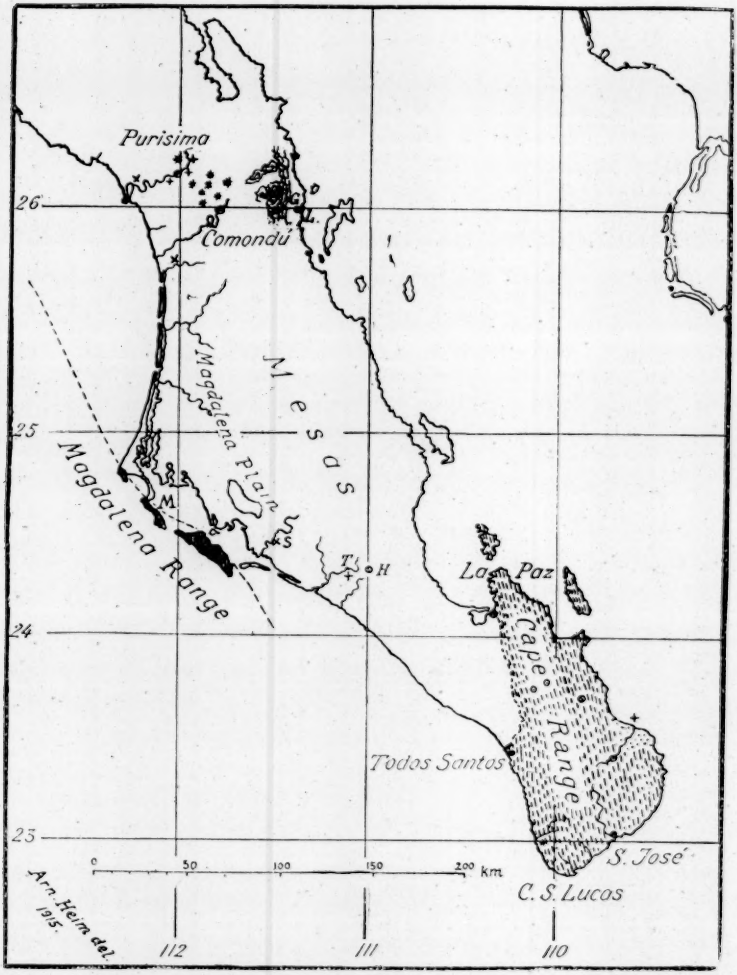


FIG. 1.—Southern part of Lower Californian Peninsula, Mexico. + Fossils of Lower and Middle Tertiary. × Fossils of Salada Formation, Pliocene. * Volcanic cones. ⊙ Towns and villages. G. La Giganta Mountain, 1,765 metres. M. Magdalena Bay. S. La Salada rancho. T. El Tepetate rancho. H. San Hilario oasis. L. Loreto.

and more rapidly descending to the Gulf coast. The characteristic form of surface is the table (Mesa) or high plateau. It is formed by sedimentary and volcanic rocks of Tertiary and Quaternary age. In this paper, special attention will only be given to the Tertiary sediments of this Mesa Region.

The exact age of some of the Tertiary formations being

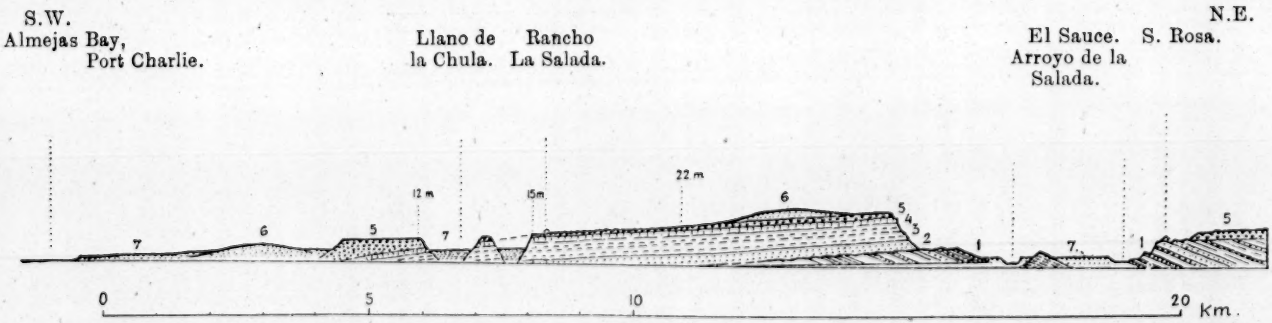


FIG. 2.—Section along Arroyo de la Salada. (Elevations exaggerated.) 1. Tepetate Formation. 2–4. Salada Formation, Pliocene; 2. Greenish sandstone; 3. Fossiliferous beds (corresponding to Nos. 2 to 9 of Fig. 7); 4. Limestone. 5. Quaternary conglomerate and sand. 6. Médanos, marine Pleistocene. 7. Alluvial soil.

undetermined, the method of the U.S. Geological Survey is followed in giving preliminary formational names according to localities. The following seven names are proposed: Tepetate (indicated on figures with T), Purisima nueva (P), Monterey (M), Isidro (I), Comondú (C), Cuesta (Cu), Salada (S).

Tepetate Formation.

In the region east of Santa Margarita Island the unfolded Salada Formation is unconformably underlain by a gently folded formation of soft greenish sandstone, hard, well-stratified gray sandstone, and greenish to violet clay several thousand feet in thickness (Fig. 2). At the ranch El Tepetate (Lat. 24° 23′, Long. 111° 8′, see T in Fig. 1) the beds of a soft greenish sandstone cross the bed of the Arroyo Colorado with a dip of 4° towards the north-east. They contain millions of a small *Orbitoides* with a central button. Professor H. Douvillé, of Paris, kindly determined them as *Orthophragmina Pratti*, Mich.,[1] and thus considers the age of the Tepetate Formation as *Upper Eocene*. Besides this species, Douvillé mentions from El Tepetate *Amphistegina Niasi* Verbeek (sub *Nummulites*), a species known from the Tongrian of the Philippines, which, however, is not of much value for the determination of age.

Following the dry bed of the Arroyo Colorado from a place three kilometres south-west of the Ranch El Tepetate towards the north-east, the following section was noted, according to the gentle north-easterly dip of the formation, upwards:—

1. At the north end of Llano del Judillo well-stratified gray sandstone weathering into hard plates with tracks of animals on the rough surface.
2. Violet and greenish clay, about 20 m.
3. Greenish shaly sandstone, about 10 m.
4. Compact soft greenish to white sandstone with black mica and many *Orthophragmina Pratti*, 20 m. (?)
5. Greenish shaly sandstone without *Orthophragmina*, about 10 m.
6. Well-stratified sandstone filled with *Orthophragmina Pratti*, about 7 m.
7. Greenish, well-stratified, shaly sandstone, about 7 m.

From El Tepetate the *Orthophragmina* sandstones were followed to the Oasis San Hilario, a distance of sixteen kilometres, where they are overlain by Quaternary conglomerates and sandstones. Farther toward the interior of the Peninsula, the greenish Tepetate Formation is directly overlain with a slight unconformity by the brown sandstone of the central table mountains, which apparently belongs to the Comondú Formation.

On the horse trail from El Tepetate, four kilometres west of San

[1] Cf. Schlumberger, *B.S.G. France*, 4me série, t. iii, p. 275, fig. A, and pl. viii, figs. 2-3.

Hilario, the underlying strata of the Tepetate Formation come to the surface, at the centre of a very gentle and wide dome-like anticline. These strata show the lithological characteristics of the typical *Monterey Shale* of California: a white siliceous shale, porous at the surface, containing brown fish scales.

It is generally known that the Monterey shale of the California districts belongs to the Middle or Lower Miocene. But this Shale of San Hilario is separated from the overlying Tepetate Formation by neither a thrust place nor an unconformity. The succession of strata west of San Hilario was noted as follows, from below:—

1. Siliceous shale, about 20 metres; base, not visible; grading into
2. Brown, hard, stratified sandstone with moulds of marine bivalves (*Chione*); thickness 2 to 3 metres.
3. Greenish, more or less sandy shale; thickness 50 to 100 metres.
4. This shale No. 3 seems to be normally overlain by the *Orthophragmina* sandstone as described above.

The question which arises from the above data so far remains unsettled: Is the siliceous shale of San Hilario to be regarded as an Eocene precursor of the Monterey shale of California, or did *Orthophragmina Pratti* survive for one or two geological periods longer in this country than elsewhere?

The Tepetate Formation is widely distributed all around El Tepetate, forming the low mountains up to the top. Again, it was observed 16 kilometres north-west of El Tepetate at the Arroyo del Liebre.

Farther north-west along the big bend of the Arroyo de la Salada in the region of the Rancho El Sauce (Lat. 24° 35′, Long. 111° 28′), underlying the Salada Formation with a perfectly visible unconformity, sediments were found which are identical lithologically, for the most part, with those south-west of El Tepetate. It is true that I did not find *Orthophragmina* here, but this may be due to insufficient collecting. Gray sandstone with tracks of animals, ripple-marks, and concretions is exposed at the Rancho Santa Rosa. Not far from this place, at Santa Teresa, a soft, somewhat leafy, greenish sandstone with small fragments of coal was found. A small hill to the south-west of that place is formed of violet, pure clay containing crystals of gypsum and shells of small Foraminifera, while still farther south-west follow rusty sandstones with ochre layers. It seems that all these strata belong to the Tepetate Formation.

All around the above-named places along the big river bend at El Sauce, the dip seems to be more or less uniform, averaging 20° to 22° toward a little east of north (Fig. 2). With a surface of three kilometres in the direction of the dip, the thickness of the Tepetate Formation thus must be at least 1,000 metres.

The facies of the Tepetate Formation seems to be chiefly neritic.

"Purisima Nueva Formation."

The only locality where this formation so far has been encountered is situated on the west side of the beautiful oasis La Purisima nueva (Lat. 26° 11′, Long. 112° 4′), where the Purisima River or Arroyo Cadegomo has cut out three small anticlinal "windows". In a previous paper on the volcanoes of La Purisima, in 1921, the writer has mapped these outcrops under the name of "Purisima Nueva Formation".

The rocks are composed chiefly of light-coloured to white sandstones with beds of broken shells (lumachelle). They are intensely compressed and folded, and thereby partly marmorized.

From the eastern outcrop, just at the western end of the date palms on the foot of the southern Mesa, fossils were found, among which are beautifully preserved Echinids.

The middle outcrop in places is very fossiliferous. Well preserved *Pecten, Turritella, Balanus*, etc., were collected on the river banks, in a straight distance of 38 kilometres west of the old Mission of La Purisima Nueva. The dip of the strata here is 70° to the west.

In an abstract of a paper by Dr. Ralph Arnold and Professor Bruce L. Clark,[1] the following statement is made:—

"Certain of the species are common to the Apalachicola horizon at a number of localities around the Caribbean Sea."

"*Pecten condylomatus* Dall is found in the Chattahoochee and Chipola beds of Florida and, according to Dr. R. E. Dickerson, is present also in the Tuxpan beds of Mexico.

"*Pecten oxygonum optimum* Brown and Pilsbry is common in the Gatun beds at Panama.

"*Raeta gibbosa* Gabb was described from the Peruvian Tertiary, and is also found, according to Dr. Dickerson, in the Miocene of the U.S. of Colombia, the fauna of which is considered by him to be a phase of the Gatun fauna.

"*Mactra dariensis* Dall is found in the Gatun beds.

"*Turritella tristis* Brown was described from the Miocene of Costa Rica."

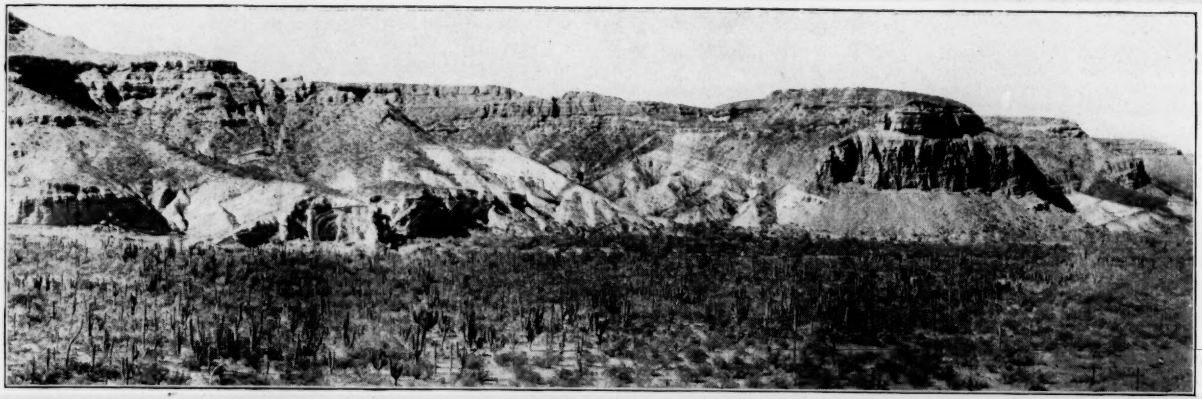
"The recognition of this fauna in Lower California is important in that it apparently indicates a direct connexion between the Pacific and Atlantic oceans somewhere in the region of Central America during the Apalachicola period of deposition."

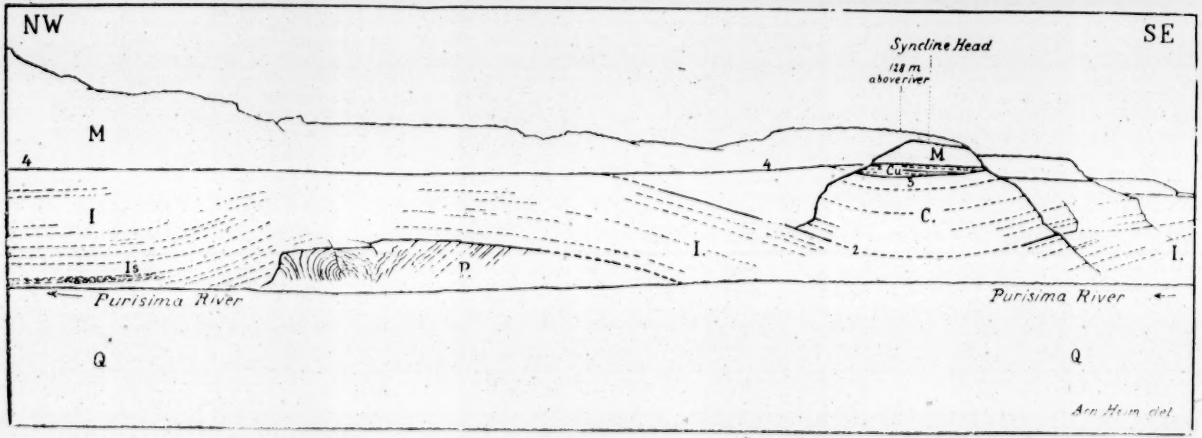
In another abstract, by R. E. Dickerson,[2] the same fossils are cited. Dr. Dickerson considers them equivalent to the Bowden fauna of the Antilles. The following quotation is taken from his paper:—

"The rest of this fauna contains casts of forms which represent typical Bowden genera. The fauna, beyond doubt, is some phase

[1] Ralph Arnold and Bruce L. Clark, "An Apalachicola Fauna from Lower California," *Bull. Geol. Soc. America*, vol. xxviii, 1917, p. 223.

[2] R. E. Dickerson, "Ancient Panama Straits," *Bull. Geol. Soc. America*, vol. xxviii, 1917, p. 230.





THE TERTIARY FORMATIONS 4–5 KILOMETRES WEST OF MISSION LA PURISIMA.

P. Purisima Inceva Formation, intensely folded ("Western Window"). I. Isidro Formation, gently folded. Is. Bluish shale with *Globigerina*. C. Comondú Formation, massive brown sandstone, 65 metres, very gently folded. M. Mesa Conglomerate, unfolded. Q. Low Terrace Conglomerate, younger Quaternary, covered with Cactus. 1–4. Unconformities, except 2, where the Comondú is locally conformable with the Isidro.

To face p. 52.]

of the Bowden or associated horizon, and straits connecting the Atlantic and Pacific at this stage of the Tertiary is thus conclusively proven. Dr. Hall has compared the Bowden fauna to that of Bordeaux and that of the Aquitanian." . . . " Dr. Hall holds that the age of the Bowden beds is late Oligocene.' Dickerson himself, however, considers the Bowden fauna as Miocene, on account of the difference of the mammalia of North and South America during Miocene time: " Thus, diastrophism indicates a Miocene age for the Bowden fauna."

The fossils mentioned above later were sent by Professor Clark to Dr. T. W. Vaughan, of the U.S. Geological Survey, who with Dr. C. W. Cooke worked over the fauna. The following statement by Dr. Vaughan is taken from a letter to Professor Clark :—

" The collection is a very interesting one, and it appears both to Cooke and me that it is the equivalent of at least a part of the *Gatun Formation* of Panama. However, I should like to be somewhat reserved in expressing this opinion until a larger collection is available.

" As there is a promise of being able to tie the Pacific Coast Tertiary formations of California to those in Central America and the West Indies through the exposures in Lower California, it is highly desirable to have more extensive investigations made in the area in which the specimens were found."

Dr. Vaughan's and Dr. Cooke's idea agrees with the correlation made by R. Arnold and B. L. Clark in that the typical Apalachicola fauna of Florida is believed to belong to the same general horizon as that of the Gatun beds.

The lithological facies of the " Purisima nueva Formation " is strictly *neritic*, partly coastal, as indicated by the frequence of *Balanus*, and totally different from the Vaquero sandstone of the uppermost Oligocene (Aquitanian) and the following Miocene beds of Upper California.

Regarding the question of classification, the unnamed U.S. geologist is in contradiction to the writer's preliminary notes: " I found that the formation outcropping in these ' windows ' west of the Mission of La Purisima is not below the diatomaceous shale, but above it, and is the same thing as the Isidro Formation, and the fossils and the lithology are the same."

The writer fully agrees that in *no* place the " Purisima nueva Formation " is visible below the Monterey. However, the following observations seemed to be against the younger age of the " Purisima nueva ".

1. The fossil beds at 3·8 kilometres west of the Mission are dipping as much as 70°, i.e. steeper than the Isidro in this region, which forms but gentle folds (Pl. XXII).

2. The Isidro Formation at this locality is overlying the marble-like beds with a strong unconformity (Pl. XXII).[1]

[1] See these white fossiliferous banks in the river-bed, and the unconformity of the Isidro on photograph Fig. 3 of the author's paper, loc. cit., 1916.

3. The fossil beds are metamorphosed in a way which was not encountered in the true Isidro.

4. The preservation of the fossils is different.

5. According to Dall, the fossils would indicate the uppermost Oligocene (Aquitanian) rather than the Miocene.

It seems to be difficult to explain Nos. 1, 3, 4, by an exceptional local pression of the Isidro Formation, and to deny No. 2. In every case it will be very interesting to obtain the demonstration of the "American" interpretation, not only by words, but with detailed sections. Unfortunately, the writer's trip was too hasty to solve the problem definitely.

Monterey Formation.

In many places along the Arroyo Cadegomo, hard, clear, siliceous diatomaceous shales were found, which resemble strikingly the well-known *Monterey Shale* (Lower Miocene) of California, U.S.A. It is the writer's opinion that one day their equivalence will be proven by fossils.

Coming from the Pacific coast, this shale was first encountered near the abandoned rancho San Ramón (Long. 112° 12′).[1] The most beautiful outcrop is that of the rocks called La Ventana (the window), where the shale is exposed all along the river as far up as the old deep well of "Casas Viejas", a distance of about 5 kilometres east of La Ventana.

At La Ventana (Pl. XXI), the shale forms a number of graceful undulations. About nine minor anticlines, with corresponding synclines, were counted, with dips of the strata up to 45° or more. The direction of the axes of the folds is north-north-east, and thus does not correspond with the general trend of the peninsula. The Ventana shales are overlain unconformably by walls of horizontally bedded rough conglomerates with marine shells. The following section was noted at La Ventana:—

(1) Yellowish to white siliceous shale, schistose, containing a bed of 1 foot of brown sandstone.

(2) Well stratified siliceous shale of white, yellowish, and violet colour, about 5 metres.

(3) A massive, white, chalk-like bank of ½ metre.

(4) Bed of brown flint, containing scales of ganoid fish and Foraminifera (*Globigerina*).

(5) Yellowish massive bed of hard, siliceous shale.

Unconformity.

(6) Marine conglomerate and lumachelle, with rolled fragments of *Lithothamnium*, probably corresponding with the Fernando Formation of California (Pliocene).

At the abandoned locality of Casas Viejas the Monterey shale, in places, is intensely folded and crushed, the strike of the axes of folds being north to north-east. The old well is located on the

[1] See geol. sketch map by the writer, loc. cit., 1921, pl. iv.

undulated shale, and is said to be drilled to a depth of 1,200 feet. At the writer's visit, in 1915, 114 liters per minute of warm salt water were flowing out of a 12 in. casing. According to Professor Hartmann, the temperature was 34·6° celsius, and the content of NaCl 4 per mille.

From Casas Viejas up the river, the Monterey shale remains below the surface unto a place on the south side of the remarkable mountain, El Pilón de la Purisima, 1 kilometre north-east of the old mission, where the river makes a knee towards the north. Here the shale seems to reach the surface for the last time. The overhanging rock of siliceous shale of this locality will be called " Canal Head ". One of the peculiarities of this outcrop is that the ordinary white or grey shale contains dark layers with traces of coal. Scales of fish and foraminifera are frequent again. The general dip is 20–30° toward the south or south-south-west. To the north-west of Canal Head the shale is somewhat faulted and crushed.

The base of the shale of Canal Head is formed by a basic intrusion, which has been described and figured in an earlier paper,[1] while at the top a gradual passage to the Isidro Formation has been noted (Fig. 3).

The thickness of the Monterey shale, on account of its irregular folding, could not be measured, but it certainly exceeds 50 metres, and may measure several hundred metres. The lithological facies corresponds exactly to that of the Californian Monterey shale, which, in the writer's opinion, is a *deposit of cold ocean water*. Indeed, the work of the Challenger expedition by the late Sir John Murray has plainly shown that the diatomaceous oozes of the present time are confined to the circumpolar regions. It seems thus, that in Miocene time a current of cold water was running down the Pacific coast as far as Southern Lower California. The regularity of stratification and the scarcity or absence of coarse psammitic intercalations seem to indicate a rather deep ocean bottom during the sedimentation of the Monterey shale. In every case, the Californian facies of this shale is in a great contrast with the facies of the younger Miocene formations (Isidro, Comondú), to which nothing similar is known in Upper California.

Isidro Formation (Miocene).[2]

The normal base of this formation was observed at Canal Head of La Purisima (Fig. 3), where the following succession was noted, beginning with the base :—

1. Intrusive basaltic rock.
2. Monterey shale as described above, about 50 metres, passing gradually into
3. Greenish shale and shaly sandstone, with layers of fine-

[1] See photograph, pl. ii, fig. 2, in the writer's publication on the volcanoes, loc. cit., 1921.

[2] " Grüne Molasse " of the writer's paper, loc. cit., 1916.

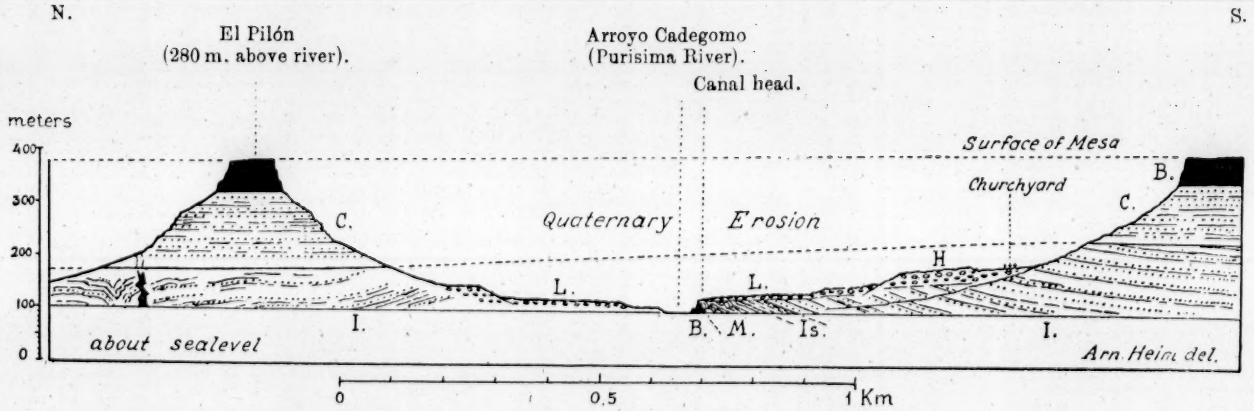


FIG. 3.—Section across Purisima Valley, about 1 kilometre east of the old mission. M. Monterey Shale. I. Isidro Formation; Is. greenish shale 20 m., Miocene. C. Comondú Formation. B. Basaltic flows and intrusions. H. High terrace conglomerate, earlier Quaternary. L. Low terrace conglomerate, later Quaternary.

grained sandstone, about 20 metres. This is the base of the Isidro Formation.

4. Greenish sandstone of Isidro Formation, about 200 metres or more, partly covered by Quaternary conglomerates.

Unconformity.

5. Comondú Formation, nearly horizontal, about 120 metres.

6. Basalt lava flow, about 60 metres thick, the same which forms the top of El Pilón.

A similar kind of passage from the Monterey shale to the Isidro Formation is seen in the river-bed above Casas Viejas, where beds of white siliceous shale alternate with greenish sandstone.

The Isidro Formation is thus apparently the normal successor of the Monterey shale.

The name Isidro is taken from the village San Isidro, which is situated on the left bank of the Arroyo Cadegomo, at 3·6 kilometres north-east of the old mission of La Purisima Nueva. About 3–4 kilometres farther up the horse trail, which follows the left side of the river, numerous fossils were found in an oyster-bed: *Chrysodomus*, *Psammobia*, *Balanus*, *Arca*, *Tellina* ?, *Chione*, *Mytilus*.

Apparently the same prolific fossil beds with *Pecten*, *Balanus*, etc., cross the bed of the Arroyo Cadegomo, a distance of two hours' easy ride further up-stream, a little south of Huerta Vieja (which means the old fruit-garden), where the Isidro Formation disappears below the Comondú Formation in the direction of the interior of the Peninsula. At this place, the nearly horizontal fossil beds are overlain first by about 10 metres of greenish shale, followed by greenish sandstone (10 metres), which in turn is covered by the brownish Comondú Sandstone.

As a whole, the Isidro Formation is formed by well stratified greenish, whitish, and yellowish sandstones with interbedded greenish shales. Crystals of gypsum are often found in the sandstones. The shales in places are flinty, and contain Foraminifera. The total thickness of the Isidro Formation is 250 metres at least. It has so far only been found for a certainty in the Cadegomo Valley from Casas Viejas to Huerta Vieja. However, looking down to the Gulf side from the watershed north of La Giganta Mountain, it seemed that the Isidro Formation again comes to the surface along the Gulf Coast north of Loreto. Possibly, the Miocene oysters found at Santiago in the Cape Region, as mentioned by Gabb, came from beds equivalent to the Isidro Formation.

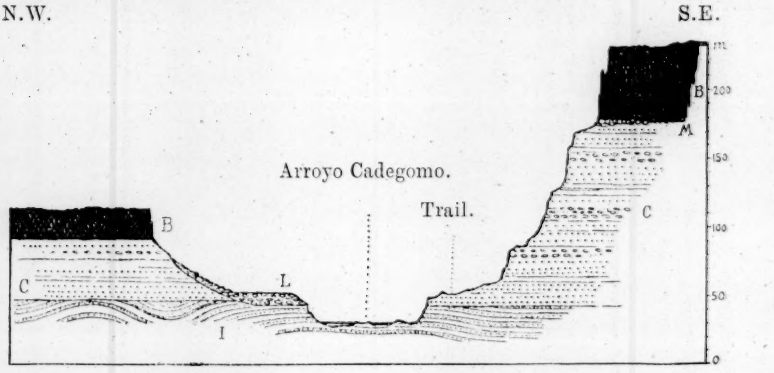
The lithologic facies of the Isidro Formation is neritic and coastal, and thus very different from that of the Monterey shale. It seems that the sedimentation occurred in warmer and shallower water. The polar current may have gradually changed its course, or diminished its force.

Lithologically, the Isidro Formation much resembles the Tepetate Formation, with which it was united by the author before finding the fossils. Possibly, they are the same.

Comondú Formation.[1]

In some places the Isidro Formation is separated from the overlying brown sandstones without unconformity, so that the Comondú Formation might be regarded as the normal continuation of sedimentation. In other localities, however, the Comondú Formation is lying with a distinct angular unconformity upon the Isidro Formation.

The name Comondú is taken from the big oasis village, which is situated at the bottom of a deep and narrow valley (map, Fig. 1), the walls of which are formed of brownish sandstone and conglomerate. These strata are nearly horizontal, and apparently belong to the same formation as the beds which overlie the Isidro Formation of La Purisima. At Comondú these sandstones and conglomerates are capped by basaltic lava of apparently the same



Base line about 100 metres above sea-level.

Fig. 4.—Section about 7 kilometres N.E. of Mission La Purisima. I. Isidro Formation. C. Comondú Formation. M. In places quaternary conglomerate below basalt flow. B. Basalt lava flows, the south-eastern on high mesa, the north-western on old terrace of Cadegomo Valley. L. Low terrace conglomerate (later quaternary).

character and age as that of La Purisima (Fig. 3, 4). The name of Comondú Formation as applied for the region of La Purisima is given with reserve, it being realized that this correlation has not yet been proved with certainty.

Taken as a whole, the Comondú Formation is composed of brownish, sometimes concretionary sandstones, with beds of conglomerate. The pebbles are formed chiefly of basaltic rocks, also tuff, sandstone, dioritic and granitic rocks. Toward the interior of the Peninsula, in Cadegomo Valley, as well as in the Comondú district, the sandstones pass into coarse conglomerates made up chiefly of basaltic rocks. The high walls of the mountain La Giganta (1,765 metres high) on the water-shed between

[1] "Braune Molasse," of the writer's paper, loc. cit., 1916.

Comondú and Loreto, are composed of heavy masses of basaltic breccia. Unquestionably, the conglomerates and sandstones have been *brought from east and north-east, where now lies the Gulf of California*. This idea was first suggested by Gabb.

The thickness of the Comondú Formation increases rapidly toward the interior of the Peninsula. At the Syncline Head of La Purisima (Pl. XXII) it was measured 65 metres, at the Pilon of La Purisima 150 metres (Fig. 3), south of Ojo del Agua (eye of water or spring) of the Arroyo Cadegomo it was esteemed to about 300 metres, and in the region of La Giganta Mountain it is even more important. The total thickness of the unfolded beds of La Giganta Mountain, including the basalt breccia, seems to be more than 1,300 metres.

No fossils have yet been found in the Comondú Formation. It seems to be a continental deposit of great extension. Indeed, it was observed by the writer along the Cadegomo River from below La Purisima (Syncline Head) to Ojo del Agua, and from Comondú to La Giganta Mountain for more than 50 kilometres across the Peninsula. Also it occurs in San Bisente Canyon, between Purisima and Comondú. As seen through the telescope, it seemed that the high mesas north-east of the Oasis of San Hilario also are formed by unfolded Comondú Formation. Finally, the coarse sandstone of Los Martires Hill at the Gulf side of the Cape Range, lat. 23° 36′, already mentioned as possibly Miocene by Gabb, and other outcrops along that part of the coast, have reminded the author of the Comondú Formation.

Although generally horizontal, the Comondú Formation has been gently folded in some places. The most beautiful fold is the syncline of Syncline Head (Pl. XXII), where the Comondú Formation, in travelling from the Pacific coast, appears for the first time in the Cadegomo Valley. Another locality where the Comondú beds are inclined is the rock called El Devisadero, to the north-east of San Isidro.

The age of the Comondú Formation is regarded as probably Upper Miocene, possibly even Lower Pliocene.

Cuesta Formation.

At La Cuesta de la Purisima, a distance of 1·7 kilometres south-south-west of the mission, the Comondú Formation, at an elevation of about 100 metres above the river, is overlain with a slight unconformity by sandstones for which the name Cuesta Formation is proposed. The lower part of the sandstones is grey, while the upper looks more brownish and resembles the Comondú Formation. They reach the " Cuesta " (= the rim of the mesa), which is at an elevation of about 270 metres above the Cadegomo River.

A similar observation was made at the Syncline Head (Pl. XXII), where the brown Comondú sandstone is overlain with a slight unconformity by the horizontally stratified grey beds of the Cuesta Formation. The thickness of the latter, at this place, is about 11 metres only.

The Cuesta Formation is known as yet only from the region of La Purisima, in a distance of 4 kilometres along the Arroyo Cadegomo. Perhaps the immense mass of unfolded beds of La Giganta Mountain, in its upper portion, contains the chronological equivalents of the Cuesta Formation.

No fossils have yet been found in the Cuesta Formation. Possibly it is a continental facies of the Pliocene.

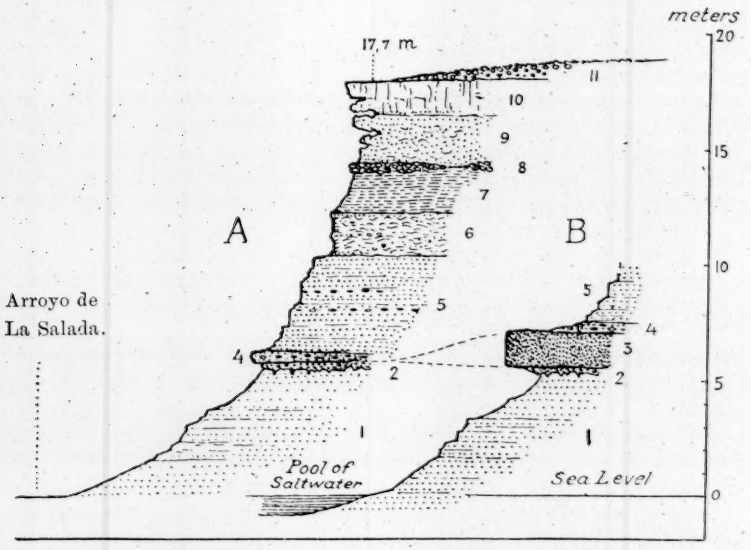


FIG. 5.—The Salada Formation (Pliocene) of Rancho La Salada. A. Section 1,400 metres N.E. of ranch house. B. Section 1,000 metres N.E. of ranch house. 1. Greenish soft sandstone, salty, apparently without fossils; rough and sharp contact toward 2. 0·3 m. gravel sand, containing basalt pebbles and many badly preserved mollusks, *Balanus*, *Turritella*, *Chione*, *Chrysodomus*, *Calliostoma*, *Oliva*, *Conus*, *Tellina*, Bryozoa, and shark teeth. 3. 1 to 2 m. bank of rough sandstone with shells of gastropodes and bivalves. 4. 0·5 m. greenish gravel sand, passing gradually into 5. 4·1 m. soft sandstone, outside grey to violet, inside greenish to bluish, containing pebbles of greenish miocene shale. 6. 1·9 m. yellow gravel sand with plenty of mollusks, also *Balanus*, Bryozoes. 7. 1·8 m. fine greenish shaly sandstone without shells. 8. 0 to 0·25 m. rough basalt conglomerate, incrusted with white lime. 9. 2·0 m. grey nodular sandstone with plenty of mollusc fragments, great *Pecten* at lower part; passing gradually into 10. 1·5 m. chalky breccious and porous limestone without shells. 11. Pleistocene Mesa Conglomerate, formed chiefly of basaltic pebbles.

SALADA FORMATION (PLIOCENE).

In the interior region of the Peninsula of Lower California (Purisima-Comondú) the youngest known marine fossil beds are of

Miocene age. Along the Pacific coast, however, marine formations of Pliocene and Pleistocene age have been found in a great extension. The most perfect section encountered is that of the cattle ranch called La Salada, at the left bank of the Arroyo de la Salada (Fig. 5).

The Salada Formation of La Salada River forms a low and unfolded plateau, which extends from La Salada Ranch as far as 15 to 20 kilometres inland, while, on the other hand, it was followed along the coast as far as Arroyo Colorado, lat. 24° 15′, a distance of 45 kilometres, wherefrom it extends still farther south-east for an unknown distance.

The lithological facies shows typical shallow-water conditions of sedimentation, as indicated by numerous fossils of coastal type, like *Balanus*, and layers of conglomerate. The fossils are abundant. However, shark teeth and *Balanus* excepted, they are badly preserved. Casts were collected of large *Polinices*, *Conus*, *Chrysodomus*, *Calliostoma*, *Oliva*, *Turritella*, *Chione*, *Tellina*, *Mytilus*, etc. The stratigraphic position, and the fossil evidence seems to indicate that the Salada Formation is of Pliocene age.

The rim of the Mesa de la Salada is formed by an unfossiliferous limestone (No. 10 of Fig. 5), which seems not to be of organic origin.

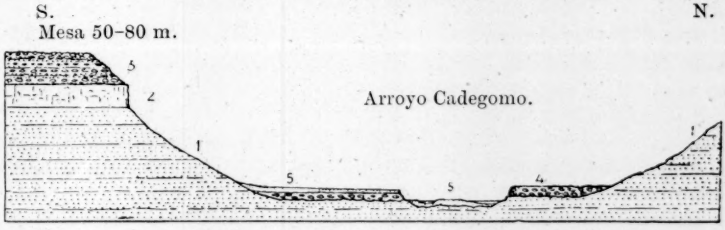


FIG. 6.—The younger Tertiary at Rancho San Ramón, near mouth of Arroyo Cadegomo. 1–2. Salada Formation (Pliocene). 1. Greenish and yellowish soft sandstone. 2. White limy agglomerate of shells. 3. Mesa conglomerate (Pleistocene). 4. Low terrace conglomerate, Younger Quaternary. 5. Alluvial soil of river bed.

Along the Arroyo de la Salada the Mesa rises gradually toward the interior, beginning with a rate of 6 to 7 metres to 1 kilometre. The thickness of Salada Formation being some 30 metres only, the Salada Formation terminates toward the interior by erosion, its substratum (Tepetate Formation) coming to the surface (Fig. 2).

Farther north, along the Pacific Coast, a very small outcrop at the mouth of the Arroyo Soledad (lat. 25° 11′) excepted, the Salada Formation is hidden below the large areas of marine Pleistocene and alluvial plains, as far as a place called Poza Grande at the Arroyo San Benancio (lat. 25° 45′), where the upper calcareous part of the Salada Formation reaches the surface again. The beds here are formed of sandstone and agglomerate of broken shells. The upper strata contain many marine gastropods, the shells of which are covered with peculiar Bryozoa. Pholad borings are found at the base.

The Pliocene of Poza Grande is covered by loose sands with marine shells of recent type, the " Medanos " of the Mexicans.

From this place farther north the Salada Formation is found in every river bed near the Pacific coast : at Arroyo Comondú (25° 49′), Arroyo Pabellon (25° 57′), at the Ranch San Ramón of Arroyo Cadegomo (26° 5′). At this latter place the green sandstone of the Salada Formation is capped by a white wall of shell breccia (Fig. 7). This calcareous horizon was followed by Mr. E. Kluth some 6 kilometres farther north-west to the mouth of the Arroyo San Gregorio, where numerous fossils were collected (*Balanus, Polinices, Chione, etc.*).

The question of termination inland of the Salada Formation along the Arroyo Cadegomo has not been solved definitely. Possibly the marine conglomerate and agglomerate of shells at La Ventana (Pl. XXI, Fig. 2) represents the shore deposit of the Salada Formation. In the higher Mesa conglomerates, more inland, no more marine shells were found. They seem to be of terrestrial origin, and possibly belong to the beginning of the Quaternary epoch. It is possible also that they are the terrestrial equivalent of the Salada Formation.

Pleistocene.

The Pliocene strata are covered along the Pacific coast by sand-hills called Médanos. They form soft waves, which may rise up to about 100 metres above sea-level. Marine shells of recent type are found frequently, like *Arca tuberculata* Sby., *Donax* cf. *cayennensis* Lam., *Tivela bryoniana* (*radiata* Dall), oysters, etc. (det. B. L. Clark). It seems that the Médanos, now quiet and covered with cactus, have been wandering dunes during Quaternary time.

For the terrestrial Quaternary see the author's publication of 1916.

Tectonic Movements.

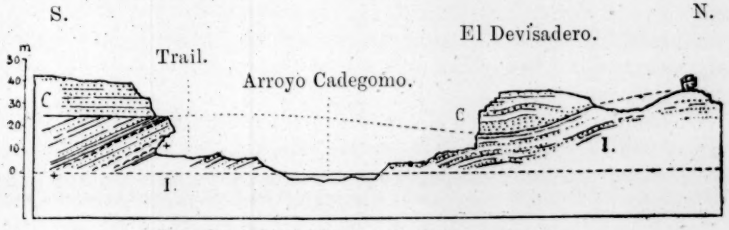
We have mentioned the *intense folding of the Purisima nueva Formation and the Monterey Formation* in the region of La Purisima. *This substructure of the Mesas is in disharmony with the general form of the Peninsula* (Pl. XXII). The axes of the folds are directed towards the north or north-east—generally north-north-east, i.e. *oblique* to the direction of the Peninsula.

The Isidro Formation (Miocene), in places being conformable with the Monterey, the folding of the Monterey must coincide with the vast unconformity below the Comondú Formation. The *age of the folding* thus is probably the *later part of Miocene.*

After the deposition of the Comondú Formation, very *gentle folding has continued locally,* as, for instance, west of La Purisima (Pl. XXII). The youngest folded formation found is the conglomerate (Pliocene ?) of Casas Viejas on Arroyo Cadegomo, where a little anticline was observed with dips up to 5°. This folding is a continuation of a fold of the underlying Monterey shale, the anticlinal dip of which reaches 15°.

Also *faulting* has occurred since the deposition of the Comondú Formation. Some 6 kilometres upstream from San Isidro, before coming to Paso Ancho, a fault cuts off the Isidro Formation against the Comondú, while the overlying basalt, of probably older Quaternary age, is undisturbed (Fig. 8).

Simultaneously with the Miocene folding a *general uplift* commenced. Indeed, the peneplain which corresponds with the unconformity below the Comondú Formation must have been preceded by such a general rising of the land. Since younger Miocene times the interior of Southern Lower California seems *not* to have been submerged again.



Base line about 100 metres above sea-level.

FIG. 7.—Section of Miocene at San Isidro, about 6 kilometres N.E. of Mission La Purisima. I. Isidro Formation, with Oyster and Turitella banks + C. Comondú Formation.

The uplift was gradually increasing towards the east, as shown by the following observations :—

1. On the watershed (La Giganta), the conglomerates of younger Miocene and Pliocene are still pointing gently upwards in the direction of the Gulf. The pebbles came from the Gulf side. This shows that the Gulf was caused by a post-Miocene subsidence (see writer's publication of 1916).

2. Marine Pliocene and Pleistocene formations were deposited along the Pacific coast.

This uplift which has caused the immense table lands still continues in the present time. Marine shells are found on the Médanos at least up to 100 metres above sea-level. The river banks are cut into the alluvial coastal plain (region of Magdalena Bay). The great " big meadow " or Llano de Yrais, on the east side of Magdalena Bay, formerly a lagoon of 100 square kilometres, is dried up, and the muddy ground of Magdalena Bay in places already reaches the surface at low tide.

The *close relation to the folding* shows plainly that the general uplift and the faulting are not independent phenomena, but *consequent* to the same tangential force which had caused the folding. The post-Tertiary uplift of the peninsula seems to balance the subsidence of the Gulf.

On the Liassic Succession of Pabay, Inner Hebrides.

By L. F. Spath, D.Sc., F.G.S.

IT is intended to give in the present paper the results of the writer's collecting in the Lower Liassic (Carixian = Lower Pliensbachian) Ammonite Beds of the Island of Pabay (Pabba), known to fame since MacCulloch and Hugh Miller drew attention to the abundance of its fossils and Murchison and A. Geikie collected its ammonites. Some of these were many years ago described by Sowerby and Wright, and in the more recent Survey Memoir [1] a list of fourteen ammonite species was given, a number trebled in the present account. Unfortunately, the hundred feet or so of micaceous, metamorphic shale at Pabay is cut up by "dolerite and basalt dykes and sills" to such an extent that the tracing of the succession is not an easy matter.

A comparison of the Pabay Lias with that of Dorset and other areas will be attempted in a second paper.

The reefs off the north-west coast of the island yielded numerous examples of *Uptonia jamesoni* (Sow.) and *Platypleuroceras brevispina* (Sow.) and their allies, but the beds are extensively faulted and, like the more barren south-east coast, did not offer a recognizable sequence. On the other hand, the reefs between the two northern extremities of the island, and those along the north-east coast, where marked "*Am. jamesoni*" on the geological 1 in. map (sheet 71, Glenelg), yielded a succession from the *ibex*, through the *jamesoni*, down to the Sinemurian *raricostatus* zone. This may be represented as follows :—

Level X_3 (Ledges east of faulted dyke at western of the two northern extremities) :—

Acanthopleuroceras maugenesti (d'Orbigny).
" aff. " "
" *valdani* (d'Orbigny).
" aff. " "
" *inflatum* (Quenstedt).
" cf. *carinatum* (Quenstedt).
Liparoceras sp. ind.
Lytoceras fimbriatum (Sowerby).

Ledges farther east, about three feet lower :—

Acanthopleuroceras aff. *maugenesti* (d'Orbigny).
Tropidoceras rotundum (Futterer).

Nine feet lower :—

Tropidoceras sp. aff. *rotundum* (Futterer).

Ten to twelve feet lower :—

Tropidoceras masseanum (d'Orbigny).

Unfossiliferous ledges follow to the east, but twenty-five feet lower were found :—

[1] "The Geology of Glenelg, Lochalsh, and South-East Part of Skye," Sheet 71. *Mem. Geol. Surv. Scotland*, 1910, pp. 182–3.

Uptonia jamesoni (Sowerby).
,, cf. *lata* (Quenstedt).

Farther east still, at
Level X_4, about thirty feet below the *maugenesti* reefs, also between the two dykes at the eastern of the two northern extremities of the island, Uptonias are very common, notably :—

Uptonia jamesoni (Sowerby).
,, *lata* (Quenstedt).
,, *angusta* ,,
,, *lacunosa* ,,
,, *margata* ,,
,, *costosa* ? ,,
,, sp. nov.

Just east of the eastern dyke
Uptonia jamesoni (Sowerby)
,, cf. *lacunosa* (Quenstedt)
still occurred, but another dyke again interrupts the succession, and six feet below this (dyke)
Level X_4a there was found :—
Platypleuroceras aff. *aureum* (Simpson).
Seven feet below :—
Uptonia cf. *obsoleta* (Simpson).
At ten, fourteen, and fifteen feet below X_4a :—
Platypleuroceras brevispina (Sowerby)
,, *molare* (Hyatt)
occurred, and, after another dyke, at
Level $X_4\beta$:—
Platypleuroceras brevispina (Sowerby)
,, sp. n. aff. *tenuilobum* (Quenstedt)
and four feet lower :—
Platypleuroceras sp. aff. *brevispina* (Sowerby).
Another dyke then follows, and perhaps ten feet below $X_4\beta$ the reefs of
Level $X_4\gamma$ yielded :—
Polymorphites quadratus (Quenstedt)
,, *caprarius* (Quenstedt)
and varieties.
At two and eight feet below occurred :—
Platypleuroceras sp. n. aff. *tenuilobum* (Quenstedt),
and, at twelve feet below, the same form and
Platypleuroceras cf. *amplinatrix* (Quenstedt).

After another dyke, at about two feet lower,
Level $X_4\delta$ the last species was again found. A second and faulted dyke follows, then come shaly beds with red nodules, similar to those of the south-west coast, to be mentioned later and yielding no ammonites. To the south-east the beach is then largely hidden by boulders and there are also numerous

dykes. Possibly six to twelve feet below the last level, when the ledges again appear at

Level X_5,

Tragophylloceras numismalis (Quenstedt),
Metoxynoticeras gen. nov.[1] *oppeli* (Schloenbach),
,, cf. *sphenonotum* (Monke).

were collected, and at two and again three to four feet below numerous nodules enclosing

Polymorphites caprarius (Quenstedt)

and allies. Shales with similar red nodules, but yielding no ammonites, follow to eight to ten feet below X_5, and at this

Level X_6 were collected :—

Apoderoceras aff. *leckenbyi* (Wright),
,, aff. *trimodum* (Dumortier),
,, sp. n. aff. *bimacula* (Quenstedt), and
quadrarmatum (Dumortier).

Five feet lower, a gigantic

" *Oxynoticeras* " sp.

was found, but another barren stretch follows, and at about sixteen to eighteen feet below X_6, and near the eastern point of the island, there occurred :—

Deroceras milleri (Wright),
,, aff. *miles* (Simpson),

forms that may already belong to the Sinemurian *raricostatus* zone. It is interesting to note that no *Echioceras* has yet been found in Pabay, but that species near to *E. macdonnelli* are somewhat abundant in Camas-na-Sgianadin, 2 miles north-west of Broadford in Skye, and north of the beds with *Asteroceras smithi* recorded by the writer.[2] There, however, no Derocerates occur.

The beds may be correlated as follows :—

X_3	*maugenesti* beds.	*ibex* zone (Oppel).
12 ft. below X_3	*masseanus* beds	*jamesoni* zone (Oppel).
Unfossilif. ledges	. . . .	
X_4, X_4a	*jamesoni* beds	
7ft. below X_4a	*obsoleta* beds	
$X_4\beta$, etc.	*brevispina* beds	
$X_4\gamma$, etc.	*Polymorphites* beds	
no Ammon.	. . . .	
X_6	*taylori* (*leckenbyi*) beds	

There may be repetition of the *Polymorphites* beds by faulting, but the relations are not very clear and, moreover, *Polymorphites caprarius* and its allies seem to have a fairly wide vertical range ; for just north of the farm on the south-west coast of the island, the

[1] Genotype to be example No. 2,141, identified with *Ammon. oppeli*, Schloenbach : " Beitr. Pal. Jura und Kreideform. N.W. Deutschl." *Palæontogr.*, vol. xiii, 1865, p. 161, pl. xxvi, figs. 4*a–c*.

[2] " Lower Lias Ammonites from Skye," GEOL. MAG., Vol. LIX, 1922, p. 172.

cliff section, starting about twelve feet above the shore-line, yielded *Polymorphites* of the *caprarius* group at the base, at three, six, nine, ten, and eleven feet up, whereas farther north, and also twelve feet above high-water mark, the same *caprarius* group was encountered at levels of three, five, six, nine, and thirteen feet up, accompanied by *Tragophylloceras numismalis* at three, five, and thirteen feet levels. Similar beds with red nodules on the shore below yielded only belemnites and pelecypods, and may correspond to the barren shales below X_4 and again below X_5. The reefs of the south and south-east coasts with their numerous dykes could not be correlated with the above sequence. It may be added that the small exposure of Pabay Shales at Tobermory in Mull yielded only *Polymorphites* of the *caprarius* group in abundance, and that some of the species of ammonites recorded by Professor Judd,[1] notably *A. oxynotus*, may be based on misidentifications. The impression of an *Echioceras* of the *raricostatur* zone, however, has been found in a pebble, off Tobermory. Conversely, the Raasay beds [2] with *Acanthopleuroceras* and *Uptonia* probably belong to the *ibex* and uppermost *jamesoni* zones, and Mr. Buckman's [3] "Wessexian" sequence, based partly on the Raasay succession, appears to require considerable modification.

Dr. Lee [4] estimated the thickness of the Pabay Shales in Raasay to be round about 600 ft., of which some 200 ft. at the top would include the *valdani–jamesoni–anguatum* zones. In the south of Strath, Mr. Barrow [5] put their thickness at fully 700 ft. The sequence in the *ibex* and *jamesoni* zones represented above, allowing for presumed repetition of certain beds by faulting, shows a net thickness of little over a hundred feet.

[1] "The Secondary Rocks of Scotland," third paper; "The Strata of the West Coast and Islands," *Q.J.G.S.*, vol. xxxiv, 1878, p. 716.

[2] "Mesoz. Rocks of Applecross, Raasay and North-East Skye." *Mem. Geol. Surv. Scotland*, 1920, pp. 70 and 81.

[3] "Jurassic Chronology," I. Lias. *Q.J.G.S.*, vol. lxxiii, 1918, p. 266.

[4] L.c. (Applecross Mem.), p. 17.

[5] L.c. (Glenelg Mem.), p. 106.

REVIEWS.

CAMBRIAN GEOLOGY AND PALÆONTOLOGY, IV, No. 7: NOTES ON STRUCTURE OF NEOLENUS. By C. D. WALCOTT. Smithsonian Miscellaneous Collections, Vol. LXVII, No. 7. pp. 365–456 + Index, pls. xci–cv, text-figures 11–23.

IN this paper, the scope of which is wider than is indicated by its title, Dr. Walcott returns to the subject dealt with in his memoir of 1918, on "Appendages of Trilobites" (reviewed in GEOL. MAG., 1919, pp. 359–63). Raymond's work on the same subject, published in 1920 (reviewed in GEOL. MAG., 1921, pp. 521–3), placed a different interpretation on the appearances seen in some of the fossils, and Walcott has now re-examined his material (not only of *Neolenus*, but also of *Calymene*, *Ceraurus*, and *Triarthrus*) in the light of Raymond's results. His conclusions are illustrated by a large number of figures reproduced from photographs, for the most part on a larger scale than those given in his earlier paper. Since the reproductions, although excellently printed, fail to give all the finer details visible in the original photographs, sets of the more important of the latter have been distributed by the author to some of the principal museums. The present writer is indebted to the kindness of Dr. Walcott for a set of these photographs, which are of unusual excellence and illustrate with great clearness the main points emphasized in this memoir.

Raymond's investigations led him to conclude that there was far less diversity in the appendages of the various genera of Trilobites than Walcott had supposed, and that they were in all cases simply biramous with the outer branch or exopodite bearing a marginal fringe of filaments. In the case of *Neolenus*, Walcott had described, in addition to the jointed leg or endopodite, an exopodite, two epipodites, and a small "exite", the form and position of these parts being as shown in his diagram reproduced in GEOL. MAG., 1919, Pl. VIII. He has now again studied his material, and has also submitted it to independent examination by three well-known palæontologists, Messrs. Ulrich, Ruedemann, and Bassler, whose joint report is printed in this paper. They conclude that the evidence for the presence of the exite and of the smaller of the two epipodites is insufficient, but they agree in identifying the larger epipodite, which, while resembling the exopodite in outline, differs from it in details of its structure.

Even more important are the divergences between Walcott's and Raymond's interpretations of those Trilobites in which the appendages are only revealed by cutting sections. In *Calymene* and *Ceraurus* Walcott attributed a very complex and remarkable structure to the limbs. His restorations of 1918 differed considerably from those which he had published nearly forty years earlier, but they agreed in assigning to each leg a pair of corkscrew-shaped appendages regarded as gills. Raymond, while admitting the

extreme difficulty of interpreting the sections, held that the appearances were not inconsistent with a simply biramous type of limb, and that the supposed spirals were due to the cutting through of a series of obliquely placed flattened filaments like those on the exopodites of *Triarthrus*. Walcott now gives a new restoration. differing in many respects from the former ones. He believes that the existence of spiral structures is fully confirmed by fresh sections, but only one spiral organ is now assigned to each leg, and it is provided with a fringe of long filaments attached one to each coil of the spiral.

The most important evidence for the existence of this remarkable structure is given by a section of *Calymene*, of which a photograph is reproduced in plate xc, fig. 1, of this memoir. The fringe of filaments is clearly shown, and the bases of the filaments are connected by a zig-zag line which might be the section of a spiral structure, but which seems much more likely to be the result of the plane of section grazing the surface of a segmented stem. The diagrams which Walcott gives to illustrate the structure of the exopodites of *Calymene* and *Triarthrus* (figs. 17 and 19) are already very much alike, and the differences between them would obviously be hard to appreciate in sections. If the fringing filaments were attached to the successive coils of an open helical spiral, it seems very unlikely that they would remain in one plane, as they are seen to do in the sections. The slightest torsion of the support would cause them to assume a helicoid arrangement. For these reasons it seems desirable to hesitate before concluding that the appendages of *Calymene* and *Ceraurus* were constructed on a plan differing fundamentally not only from those of *Triarthrus* and *Neolenus*, but also from those of every other Arthropod, living or fossil, of which the structure is known.

Many other points of interest and importance are discussed in this memoir, and the further investigations on the same subject, which Dr. Walcott promises, will be eagerly looked for by all students of Arthropod morphology.

W. T. C.

A Bibliography of South African Geology. By A. L. Hall. Memoir No. 18, Geol. Survey of the Union of South Africa, pp. 371. Pretoria, 1922. Price 10*s*. 6*d*.

MOST geologists are well acquainted with the admirable bibliography of the same subject by Miss Wilman, published by the Philosophical Society of South Africa in 1905. The present work brings the bibliography up to the end of 1920, incorporating the whole of Miss Wilman's references and much new material supplied by her, as well as the author's own collections. The result is a list of 5,794 items. The term " geological literature " has very wisely been interpreted in a liberal sense to include many more or less casual references to geology in writings mainly dealing

with other matters. The geographical term "South Africa" is also used in an extended way, so as to include not only the whole of the Union, but also Rhodesia, South-West Africa, Angola, the Belgian Congo, the territory formerly known as German East Africa (the Tanganyika Territory of the present time), Madagascar, and Portuguese East Africa. In South Africa in this wide sense, more perhaps than in any other country, owing to the special economic conditions and the dominant position of the mining industry, geology plays a prominent part in the general life and thought of the people, and some knowledge of it is almost universal. The work cannot fail to be of the greatest use to geologists interested in this large section of the continent, as well as to others dealing with more general problems, on many of which South African studies have thrown so much light.

R. H. R.

Rocks and their Origins. By Professor G. A. J. Cole, F.R.S. pp. viii + 174, with 20 illustrations. Cambridge University Press, 1922. Price 4*s*.

AT its first appearance in 1912 this book afforded an admirable summary of the facts and theories derived from the study of rocks up to that date. We have recently received for review a copy of the same work bearing on the title-page the date 1922 and the impress "Second Edition" on the fly-leaf and on the paper jacket. A careful collation of this with an original copy of 1912 has revealed, besides the alteration of date, a slight modification of the last sentence of the preface and the replacement in the bibliography of an English work by an obscure German periodical, dated 1911, which will be inaccessible to the vast majority of readers. Otherwise the two appear to be absolutely identical.

In the last ten years the study of rocks has made great advances; in particular the detailed petrography of the sediments may be said to have come into being within that period, and the investigation of the origins of both igneous and metamorphic rocks has made great strides. This book therefore, though excellent as far as it goes, is in no way up to date. It is much to be regretted that the publishers have not taken the opportunity of bringing out a real new edition, setting forth in the same attractive style the recent great advances in petrology.

An Introduction to Sedimentary Petrography, by H. B. Milner. pp. 125, with 15 plates (not numbered), 7 text-figures, and a table. London: Murby, 1922. Price 8*s*. 6*d*.

THIS book has been written mainly as a help in the study of loose detrital sediments, a branch of petrography which has greatly increased in importance of late years in connexion with numerous

economic applications, and shows considerable promise in the correlation of sands in oil regions. The first chapter deals briefly with methods of sampling, treatment, and microscopical examination. One would rather like some further elucidation of the statement that "microchemical reactions are inadmissible with detrital grains". The author insists very strongly on the necessity for elutriation for the separation of the finer fractions, but apparently omits to point out that it is usually impossible to determine the mineral character of the finest grades. It is unlikely that these will ever be of much use for correlation purposes. The mineralogy of the finer-grained sediments is still in a very unsatisfactory state in spite of the admirable pioneer work of Hutchings. Nearly half of the book is occupied by tables of the physical and optical properties of the minerals commonly occurring in sands, illustrated by useful drawings, the work of Mr. G. M. Part. The last two chapters discuss in a somewhat sketchy manner the principles of petrographic correlation of sediments and the bearings of sedimentary petrography on palæogeographical problems. There is a useful bibliography, which, however, is mainly confined to British publications.

REPORTS AND PROCEEDINGS.

British Association, Hull.

Section C.—Geology.

Discussion on Wegener's Hypothesis of Continental Drift. (*a*) Opener, Dr. J. W. Evans, F.R.S.

The occurrence of allied forms of life on continents separated by great oceans has given rise to speculations as to former connexions between them. There is in some cases also considerable similarity in the geological features on the opposite sides of the oceans, especially in the case of the Palæozoic rocks of the two sides of the Atlantic, and of the Permo-Carboniferous formations of India, Australia, South Africa, the Falklands, and South America. It was, however, primarily to solve the distribution of life forms that Dr. Wegener formulated his hypothesis of the dispersion of the continental masses. He supposes these to have been aggregated together as late as the Tertiary period, and North America to have been in close proximity to Europe even in the Pleistocene. The continents are, he thinks, slowly drifting from the poles, and from east to west. The former movement is believed by him to be proved by observations at European observatories and at that at Washington, showing a decrease in latitude, but recent observations on the Pacific coast indicate that latitude is there increasing. He is under the impression that America is going west faster than Europe, and that the longitude of Cambridge, Mass., is increasing, while

Greenland is moving in the same direction at a still more rapid rate. The continents are composed largely of rocks rich in silica and alumina, "Sial," while those below the sea are less siliceous and heavier, and have been referred to as "Sima". This extends under the Sial of the continents at a depth which Wegener estimates at 57 miles, which is probably far too great. He believes that the Sial masses drift through the Sima, like icebergs through the sea. The Sima is probably, however, a crystalline solid down to a depth of about 15 miles, and is as strong as, if not stronger than, the Sial.

By overthrusts and crumpling some areas are brought nearer together, and by fissuring, igneous intrusions, and normal faulting others are moving apart. There is some evidence of a slow drift away from Africa and towards the Pacific, but there is nothing to show that this has been as rapid as is assumed by Dr. Wegener. The Atlantic may have come into existence since Carboniferous times, but this would not mean a separation equal to its whole width, as part of the submergence would be caused by faulting down towards a region of tension.

The Astronomer-Royal of Scotland has shown that determinations of longitude by telegraphy are subject to serious errors. Light is thrown on this by the observations of Hecker and others with horizontal pendulums. In addition to the movements caused by the variations of direction and amount of gravity due to the sun and moon, there are others of greater amplitude, due to diurnal tilting as the result of solar radiation. Similar seasonal effects must also occur. Variations of the barometer in adjoining areas, and of the underground water-level and marine tides, must also affect the pendulums. Most of these effects are considerably less at some depth below the surface, and it is suggested that the instruments employed should be placed in excavations and protected from disturbing influences. They should be located in plains with uniform geological structure and surface character.

(*b*) Professor H. H. Turner, F.R.S.—The Astronomical Evidence bearing upon the Hypothesis.

The only piece of astronomical evidence supporting Wegener's hypothesis, and worthy of serious consideration, is the apparent drift of Greenland. The observations in 1870 and 1907 show a change of 1,200 metres, and observations in 1823 lend some support, but it cannot be said that the drift is established beyond doubt, though a good case is made for repeating the observations to-day; indeed, the matter is so important that this is a duty. All the other evidence is practically against such changes in modern times.

(*c*) Mr. W. B. Wright.

A critical comparison of the geological formations on the two sides of the North Atlantic shows on the whole a very remarkable correspondence, both stratigraphical and palæontological, from the Pre-Cambrian up to the Cretaceous, and in particular brings to light

certain facts even more strikingly indicative of a former *rapprochement* between the two continents than any pointed out by Wegener.

The recurrence in America, on opposite sides of the old Appalachia, of the two facies of the European Cambrian and early Ordovician, which are here separated by the Caledonian chain, is perhaps the most striking, the lithological and faunal distinctions and the sequences of transgression and recession, different on either side of the chain, being reproduced with remarkable precision. Again, the continental and marine facies of the Devonian are separated in both countries by boundaries which become conterminous on the Wegener reconstruction.

The equivalent line in the Triassic lies further south both in Europe and America, but, as it passes into the areas of generally defective correspondence in Spain and Central America, is less valuable as a criterion. It should, on the other hand, be noted that in America there are in the middle of the Carboniferous and Cretaceous formations marked unconformities which have not been recorded in Europe. The investigation of these discrepancies, perhaps more apparent than real, might well form a test case for the theory.

Discussion on The Geological History of the North Sea Basin. (*a*) Opener, Professor P. F. Kendall, President of the Section.

The North Sea is situated upon an area of very ancient and persistent depression, dating probably from Permian times. Coal-measure rocks dip into the Basin in Belgium and Holland, north of the anticline of Brabant; probably in Lincolnshire; and certainly in Durham and Northumberland; they re-emerge at Ibbenbüren.

The Permian rocks of Yorkshire and Lincolnshire increase steadily in thickness from west to east. The Triassic rocks show no significant change. Members of the Jurassic and Cretaceous series attain their maximum development in Britain in the area bordering the North Sea, and the Lower Cretaceous beds exhibit a deep-water phase absent elsewhere in Britain. The Chalk thickens north and east of London, partly by preservation of higher zones, and partly by general expansion. In Yorkshire zone for zone it reaches its maximum development, but in a deposit of this type this may not indicate contemporaneous movement.

The renewal of the Armorican movement in the South of England, Northern France, and Belgium appears to have begun after the deposition of the London Clay and Woolwich Beds, and after some interruptions to have resumed its activity at or about the beginning of Pliocene (Diestian) time. This may be regarded as the first appearance of a North Sea as we know it.

Harmer has suggested a coast-line connecting the Lenham and other outliers spanning the Straits of Dover, joining up with the main Diestian outcrops of Belgium. This view is accepted by the Belgian geologists and accords generally with my own judgment, though not without some reservations. This may be the stage repre-

sented by Barrow's High Level (Pliocene) Gravel of the London Basin, which seems to belong to a period prior, as he believes, to the great denudation.

This, then, would be the western embayment of the North Sea.

A movement *en bascule* seems to have ensued, resulting in a general but intermittent uplift on the English side and along the axis of Artois, with a complementary slow depression of Northern Belgium and Holland. Great denudation of the British Diestian, and probably some Miocene, ensued, and the Coralline Crag, probably an offshore shoal in 20 or 30 fathoms of maximum depth, was accumulated upon an eroded surface of Lower Eocene; but its gravelly base obtained the coarse scourings of London Clay, ? Miocene, and fossiliferous concretions of a sandstone near to the Diestian in age.

On the Belgian side depression seems to have been almost continuous.

The Coralline Crag was uplifted and subjected to severe subaerial and marine erosion, and the Red Crag overlapped it on the English and Belgian sides.

With the earliest Red Crag, that of Walton-on-the-Naze, the record becomes practically continuous. Steady uplift was taking place in the south, throwing the coast-line farther and farther north. Harmer recognizes three stages, but many more could be distinguished by the progressive changes in the fauna—the elimination of Southern types and the incoming of Northern.

The Norwich Crag comes in north of a ridge of Coralline Crag at Aldeburgh, and appears to represent a very slightly more modern phase than the Red Cragflanking the ridge on the south.

Chillesford Sand and Clay surmount the Red and Norwich Crag from Essex upward.

Harmer regards them as the deposits of a winding estuary of the Rhine.

A renewal of the "Crag" type of deposition, the Weybourn Crag, with *Tellina balthica*, was succeeded by a definite estuarine series, the Cromer Forest Bed. It begins with the Freshwater Bed, in which a flora comparable to that of Norfolk to-day is found. This is followed by a marine deposit with Arctic shells, and above that a second freshwater bed with an Arctic flora.

This series may rest directly on the Chalk, an effect of the continued upward tendency on the English side of the sea.

In Holland the whole Pliocene series is probably present, and the great thickness of comparatively shallow-water deposits prevailing down to 1,100 feet at Utrecht bespeaks a continual downward tendency of the Low Countries.

The evidences of Pliocene conditions further north are extremely scanty, in fact, only near Hartlepool, where Trechmann has found a pre-Glacial plant-bed, is there any relic of Pliocene deposits in their native position.

At Sheringham Mr. Stather has found a block, doubtless from the

Drift, of Red Crag of about Newbournian date of a type unknown elsewhere.

In Holderness the Drift has yielded *remanié* fish remains, evidently derived from the Red Crag, and in Aberdeenshire in the Slains gravels Jamieson found a large suite of rather fragmentary shells of mainly early Red Crag facies, mingled with some undoubted Pleistocene forms.

The Cromer Forest Bed stage is the latest pre-Glacial stage recognized in East Anglia, but in Yorkshire a well-defined cliff-line bounding a broad plain of marine erosion is traceable, which appears to be, in part at least, of later date.

The cliff begins at Sewerby between Bridlington and Flamboro Head, and has been traced by Mr. Crofts and myself round to Hessle, near Hull. The corresponding beach has been seen at each end. Borings have enabled the old sea-floor in front to be charted and contoured.

The next phase was a retreat of the sea and formation of sand dunes along the foot of the cliffs. The geological date is indicated by the occurrence of *Elephas antiquus*, *Rhinoceras leptorhinus*, and *Hippopotamus* in the deposits.

This fauna accompanies implements of Chellean type in the South of England.

The next episode was the arrival of a great ice-sheet having its radiant point in the neighbourhood of the Gulf of Bothnia. This appears to have displaced the water from the whole of the North Sea as far south as the coast of Essex, if no further.

Several retreats and readvances took place, and the final retreat can be traced with great detail and precision by the drainage phenomena developed along the margin of the ice up to its last contact with the British shores on the Ord of Caithness. Oscillations of level accompanied the retreat and raised beaches were left, especially north of the Tweed, but on the completion of the withdrawal the land stood about 80 feet higher relatively to the sea than at present. The southern portion of the North Sea became a marshy plain, over which great rivers such as the Rhine, Thames, and Weser took a meandering course. Peat bogs occupied much of the area, and forests clothed the margins.

A depression to the present level then ensued, and the great shallow bay of the North Sea south of the Dogger Bank was formed. Only in a few places does its depth exceed 25 fathoms. The sea ran up the estuaries, and thus the Humber itself and its branch the Hull came into being.

A true scale of the breadth and depth of the North Sea in this latitude can be obtained by taking a piece of No. 40 sewing cotton 13 ft. 8 in. in length. Knots tied in the cotton would represent Heligoland and any of the " pits ".

Dr. Herbert L. Hawkins.—The Relation of the River Thames to the London Basin.

(i) The London Basin is an asymmetrical syncline pitching eastwards. The southern rim dips sharply, the northern gently, the axis lying nearer the south. Drainage of such a district would consist normally of a main stream along the axis with tributaries on both sides. This condition is realized in the west by the Kennet and in the east by the Thames below Chertsey. In the intervening portion (Theale to Chertsey) the main stream is north of the "ideal" position, and its southern tributaries cross the axis and flow against the dip. At Wargrave the Thames returns into the Chilterns in apparent defiance of all rules and reason. There is evidence that the southern tributaries have postponed junction with the main stream fairly recently, and that the Thames itself has shifted its course southwards.

The original drainage of the basin is believed to have passed along the Kennet to Theale, thence to Pangbourne, along the present Thames to Windsor, thence by Rickmansworth and Hertford, and probably down the Lea. (Possibly it reached the sea past Maldon or Colchester.) These broad meanders were reversible with similar amplitude. This line was probably the synclinal axis in Miocene and Pliocene times, its southward displacement being due to the increased plunge of the "North Downs" dip. Many anomalies in the drainage and river deposits are explicable on this hypothesis, the rivers being incompletely adapted to the tectonic change.

(ii) The Upper Thames is a tributary of the London Basin drainage. New sections in Goring Gap show that torrent-action has deepened the gorge by about 50 feet. Excavations on the hills above Whitchurch afford presumptive evidence of the marginal effects of true glaciation. The nature and arrangement of the drift, the numerous lateral channels, and the character of the gorge itself, are such that their occurrences further north would be ascribed generally to glacial action.

It is postulated that a Welsh-Midland ice-sheet reached the Chalk-scarp, but failed to override save at the lowest parts. One such part was in the angle between the Chilterns and Berkshire Downs; the final excavation of Goring Gap was achieved by the outflow from a retreating ice-tongue that had penetrated into the London Basin. The relatively early date of the glaciation and the softness of the bed-rocks account for obscurity of details.

ANNOUNCEMENTS AND INQUIRIES.

Mr. Arthur T. Hopwood, B.Sc., Geological Department, the University, Manchester, is engaged on an investigation concerning the structure and affinities of *Cyclus* de Koninck. Mr. Hopwood would be pleased to receive, on loan, any specimens from British or foreign localities, and will return such specimens to their owners as soon as possible.

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